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FINAL REPORT ON GRANT NAGW-3457

1. PREAMBLE.

A supplemental increment was given for grant NAGW 3457 to aid in winding up the work that was done under this award. The work that was to be undertaken under this supplemental increment included the following: an analysis of the terms that are responsible for the thermal balance in the upper atmosphere; an analysis of the terms responsible for the electron structure of the ionosphere. These studies have been continued, the results of the first effort has been published in the Journal of Atmospheric and Terrestrial Physics. Results from the second effort were presented at the Fall AGU meeting in San Francisco. Work was also continued in determining the nature of the build up of NO during geomagnetic storms. Some aspects of this work was presented in Birmingham, England.

2. INTRODUCTION

The Earth's mesosphere and lower-thermosphere/ionosphere (MLTI), between ~60 and 180 km altitude, is the most poorly understood region of the Earth's atmosphere, primarily because of its relative inaccessibility. This lack of knowledge has been widely recognized and has provided important scientific rationale for the upcoming NASA TIMED mission [*Killeen et al.,* TIMED Science Definition Team, Volume II, 1991]. While the data gathered during the TIMED era will revolutionize our understanding of the MLTI region, much work can be done prior to the mission, both to develop data-analysis and modeling techniques and to study the more limited relevant experimental data from previous missions. The grant reported on here continues and extends an existing successful program of scientific research into the energetics, dynamics and electrodynamics of the MLTI, using available theoretical and data analysis tools.

In the work reported here, we proposed a one-year effort to wind up the work proposed under the original NAGW 3457 grant. Three studies were included in the statement of work. The studies were:

• A paper on heating term analyses using output from the NCAR-TIGCM was to be completed. This was intended to enable us to look at the physically significant terms that are responsible for the temperature structure of the Earth's upper atmosphere.

• A similar analysis was to be undertaken for ions. This analysis was to be continued. This investigation was to include studies of the reasons why O^+ densities in the upper thermosphere change.

• Studies of geomagnetic storms and their effects on the neutral circulation, thermal structure and composition were to be continued.

3. SCIENTIFIC ACCOMPLISHMENTS.

The paper on the heating term analysis is currently in press and will be published in the March issue of the Journal of Atmospheric and Terrestrial Physics. This paper uses post processor output from the NCAR-TIGCM to describe the physically significant terms that are responsible for the thermal structure of the upper atmosphere. The main conclusions from this study were:

1) The lower thermospheric heating and cooling terms have complex morphological dependencies on latitude, longitude, altitude, geomagnetic activity, and season.

2) Near 180 km the most important heating term in day time is that resulting from the chemistry of the minor species, with direct solar EUV heating and heating resulting from electron-ion collisions having a secondary role. At high latitudes Joule heating dominates all other heating terms. Cooling results primarily from a combination of adiabatic expansion, NO radiation and downward heat conduction.

3) At about 125 km altitude direct insolation in the Schumann-Runge bands and continuum and, at high latitudes, Joule heating dominate the heating terms, but compressional heating does make a significant contribution in the winter hemisphere. Radiation from NO and CO_2 molecules dominates the cooling terms at this altitude, with

the two terms being roughly commensurate. However adiabatic expansion is an important cooling term in the high latitudes of the summer hemisphere.

4) Direct solar insolation, heat conduction, and compressional effects dominated the heating terms at the lowest altitude (~103 km) described in the paper. The dominant cooling terms was radiational cooling by CO_2, with heat advection and adiabatic expansion in summer playing minor roles.

Work also was undertaken on the preparation of a paper on the terms responsible for structure of the ionosphere. Another related paper is being prepared which deals exclusively with the formation and development of the Appleton anomalies during the day. These papers will shortly be submitted to the Journal of Atmospheric and Terrestrial Physics.

Several conclusions have been drawn in the first of these two papers. These are:

1) Daytime middle-latitude production O^+ densities below the F_2 peak are dominated by production by photoionization and loss by chemical reactions.

2) Above the peak ambipolar diffusion becomes the most important term.

3) The main features of the Appleton Anomalies are reproduced in the NCAR-TIGCM output, with the winter peak developing first in the morning, and the summer peak developing later.

4) NO is an important broker species in determining the ion composition of the E-region.

The second paper is not quite as developed as the first, but results from it were presented at the Fall AGU in San Francisco.

The work on geomagnetic storms is less developed. Discussion of the effects of the build up of NO during these times was included in the heating term paper, and further investigations of these effects were included in presentations given at the COSPAR and the Western Pacific AGU meetings in July. In addition, work has continued on studying the seasonal differences in the response of the thermosphere to geomagnetic storms using the DE 2 data.

4. CONCLUDING REMARKS.

In the three year period of this grant we achieved the scientific goals that were described in the statement of work.

5. REFERENCES

Killeen, T. L., H. G. Mayr et al., The Final Report of the TIMED Science Definition team. Volumes I, II and III, Space Physics Division, NASA Headquarters, July 1991

APPENDIX 1.

PUBLICATIONS DURING THE GRANT PERIOD.

Wu, Qian, T. L. Killeen, W. Deng, A. G. Burns, J. D. Winningham, N. W. Spencer, R. A. Heelis, and W. B. Hanson, Dynamics Explorer-2 satellite observations and satellite track model calculations in the cusp/cleft region, J. Geophys., Res., 101, A32, 5329, 1996.

Garner, T. W., Killeen, T. L. , Burns, A. G., Coley, R. and Winningham, D. W., An examination of the oxygen red line signature of a polar cap ionization patch as seen from the Dynamics Explorer 2 satellite, Radio Science, 31, 607-618, 1996.

Killeen, T. L., A. G. Burns, I. Azeem, S. Cochran, and R. G. Roble, A theoretical analysis of the energy budget in the lower thermosphere, *in press* J. Atmos. Terr. Phys., 1997

Wang, W., T. L. Killeen, A. G. Burns and R. G. Roble, A high-resolution, three dimensional, time dependent, nested grid model of the coupled thermosphere-ionosphere, *in press*, JATP, 1997

Burns, A. G., T. L. Killeen and R. G. Roble, Processes that cause changes in ion density: I. Quiet geomagnetic conditions, for submission to J. Atmos. Terr. Phys., 1997.

APPENDIX 2.

PRESENTATIONS GIVEN DURING THE GRANT PERIOD.

The role of ionosphere-atmosphere coupling in the energy budget of the mesosphere-lower thermosphere, T. L. Killeen, and A. G. Burns, Invited paper, COSPAR, Birmingham, 1996.

Thermosphere-ionosphere modeling and its use as a predictive tool for Space Weather Applications, T. L. Killeen, A. G. Burns, W. Wang, R. M. Johnson and R. G. Roble, Invited paper, COSPAR, Birmingham, 1996.

New thermospheric modeling tools, T. L. Killeen, A. G. Burns and W. Wang, Invited paper, Western Pacific AGU, Brisbane, 1996.

The application of a postprocessor for the NCAR-TIGCM to a study of the Appleton Anomalies, A. G. Burns, T. L. Killeen, and R, G, Roble, AGU San Francisco, December 1996.

Mid-latitude F-region post sunrise electron temperature enhancements calculated by the Thermosphere-Ionosphere Nested Grid (TING) model, W. Wang, T. L. Killeen, A. G. Burns, and R, G, Roble, AGU San Francisco, December 1996.